Automatic mesh generation in wind farm design and management

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Abstract

We propose a new automatic procedure to generate hybrid meshes to simulate turbulent flows for wind farm design and management. In particular, numerical modeling of wind farms involves a RANS simulation of the Atmospheric Boundary Layer (ABL) flow and modeling the turbines using the actuator disc theory. Therefore, the generated meshes have to fulfill several geometrical requirements to answer to the different modeling features. They must: capture the topography features that can influence the wind flow; have a boundary layer close to the terrain to resolve the ABL; be conformally adapted to the disc (turbine) to simulate the turbine effects on the wind flow; be adapted around the disc to capture the wake effect; and present a smooth mesh size transition around the disc to conform the element size of the ABL mesh, in which the turbines are immersed. We highlight that the mesh generation procedure is fully automatic once given the mesh size, a topography description, the wind inflow direction, a list of turbine insertion points, and the turbine models.

Problem statement

Input

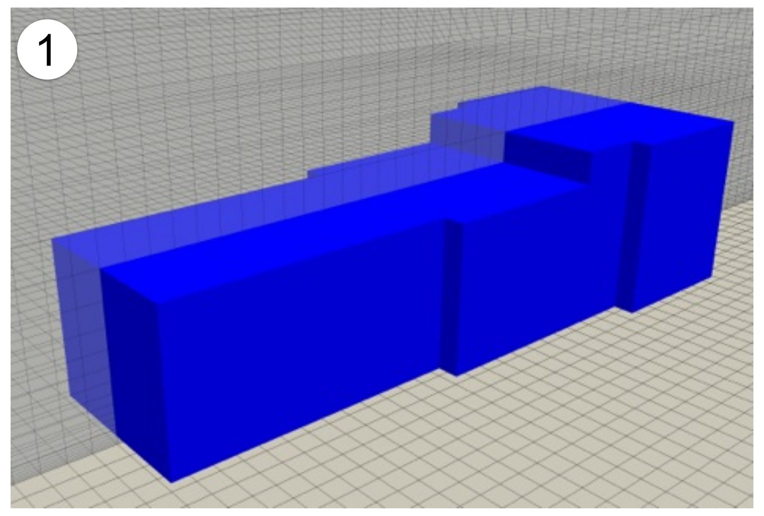
- Topography description
- Geostrophic wind inflow directions (typically 16 different directions)
- Wind turbine locations
- Turbine height and diameter
- Element size

Output

One hybrid mesh for each inflow direction, where:

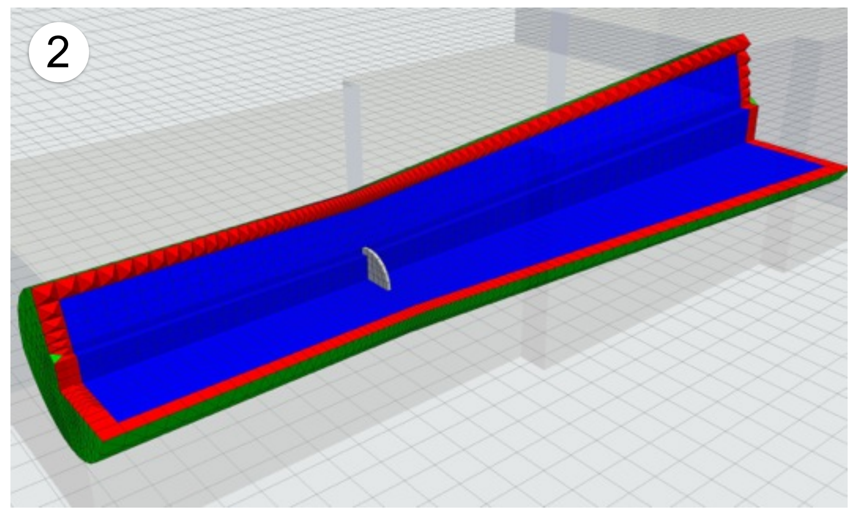
- the background hexahedra are aligned with the wind direction,
- the surface mesh conforms the topography
- the Atmospheric Boundary Layer is reproduced, and
- the mesh is adapted around each turbine to capture the wake and upwind effects.

Hybrid meshing for wind farms



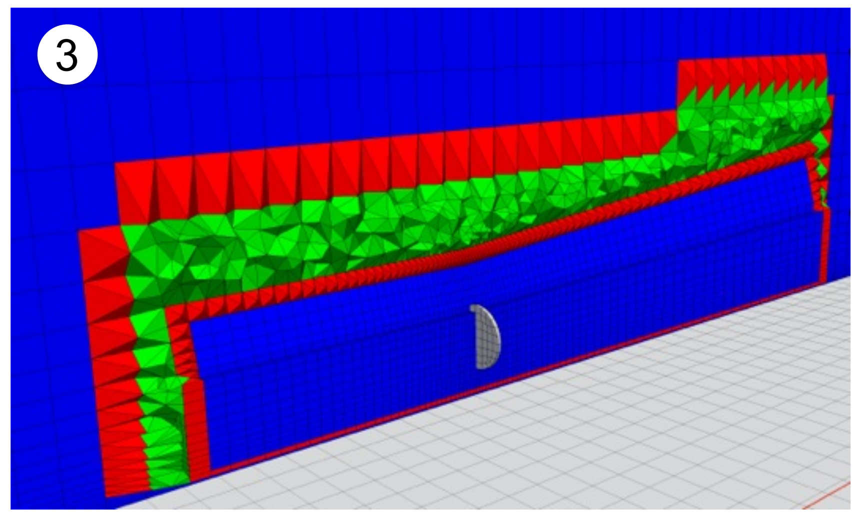
Generate background hexahedral mesh:

- Conforming the topography.
- Sweeping the surface mesh [1].
- Resolving the Atmospheric Boundary Layer.
- Optimizing both the quadrilateral mesh on the topography and the hexahedral mesh to obtain high-quality orthogonal elements [2].



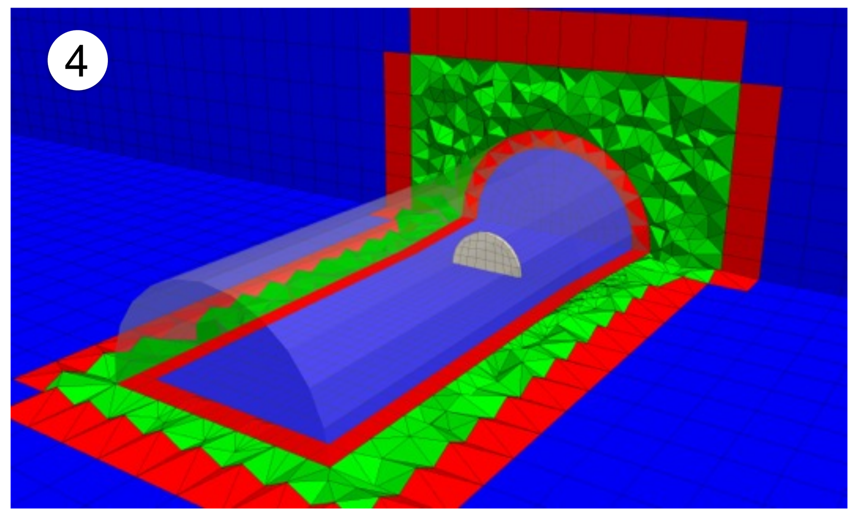
Insert the discs in the wind turbine location and generate an adapted hexahedral mesh of the wind around the disc:

- Mesh size transition in the downstream (upstream) direction to capture the wake (upwind) effects and to smoothly match the background mesh size.
- Mesh size transition in the radial direction of each disc also required.



Generate tetrahedra and pyramids to conform both hexahedral meshes:

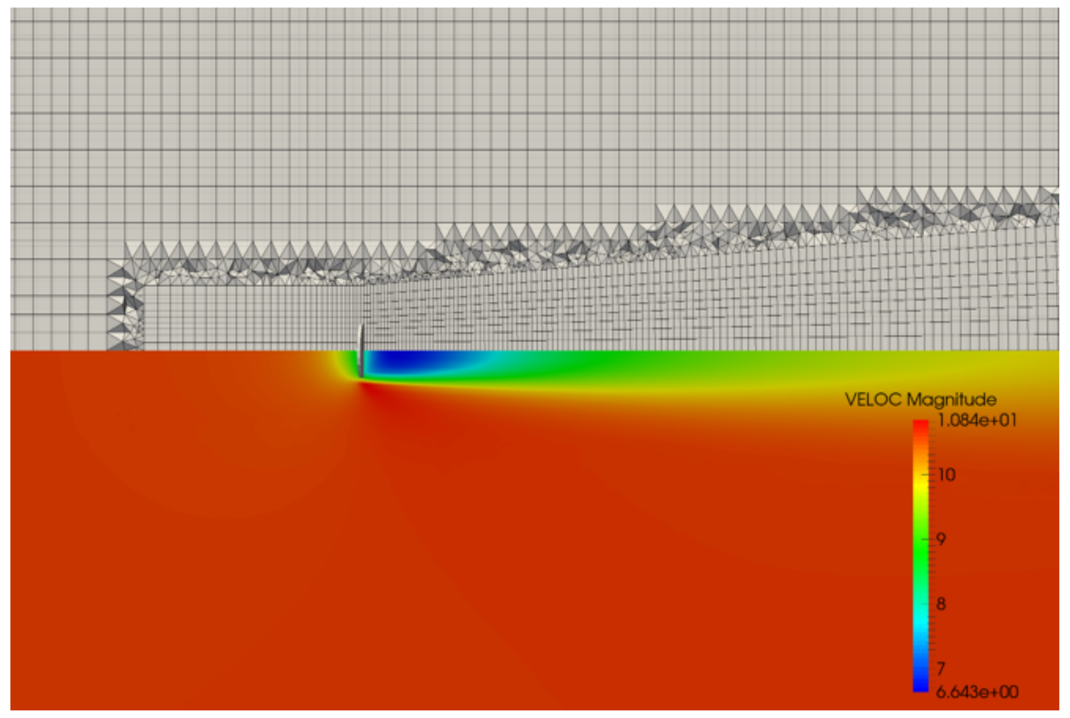
- Generate a transition layer of pyramids/tetrahedra, using different templates depending on the shape/location of the initial hexahedra [3].
- Conform the inner and outer meshes with tetrahedra. To fill the gap between the two meshes we use the TetGen meshed [4].

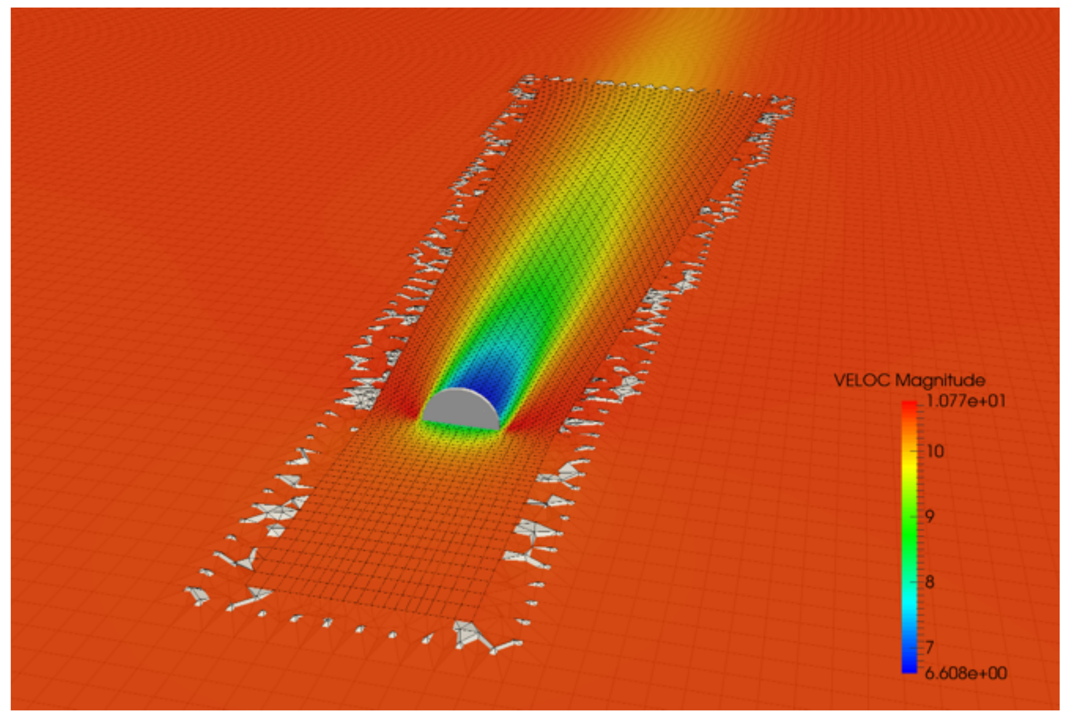


Optimize hybrid mesh:

- We use the ideas presented in [2] for high-order elements to define distortion/quality measures for hexahedra/pyramids
- We relocate the nodes to improve the element quality, minimizing the distortion of the hybrid mesh.

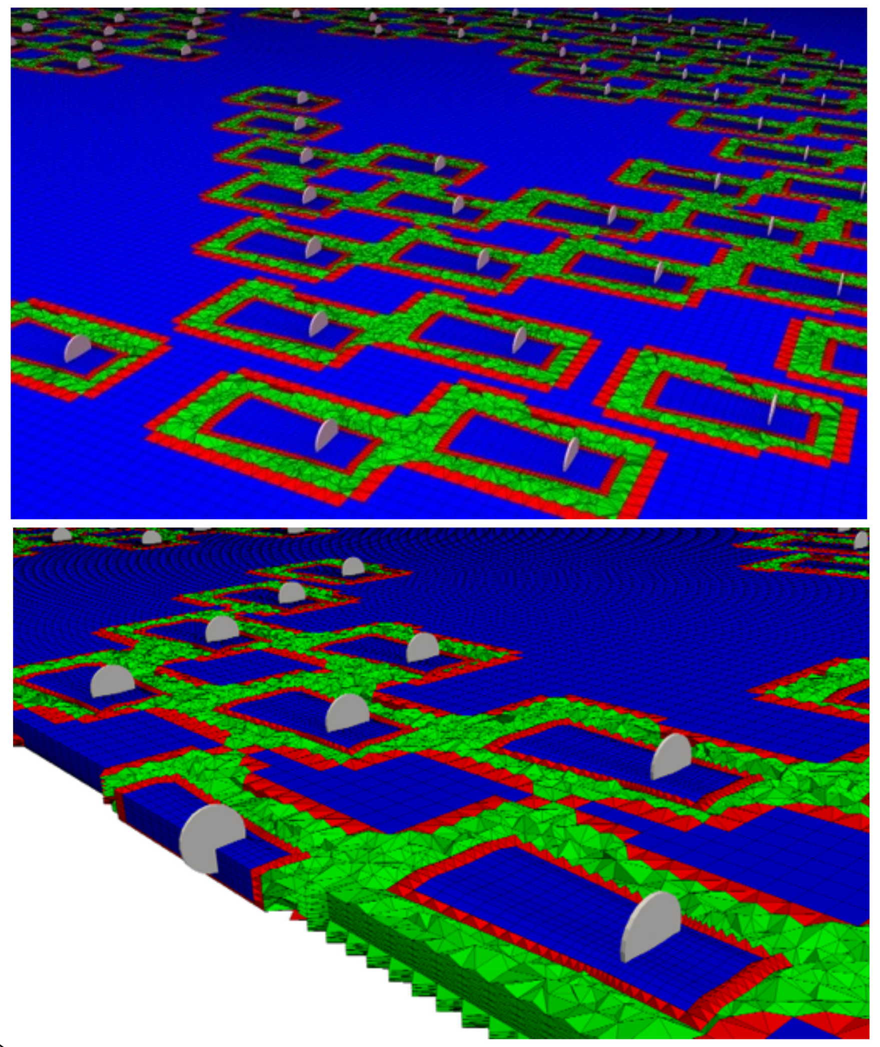
Close up of the mesh around a turbine and test simulation (offshore wind turbine in Denmark, Sexbierum wind farm)





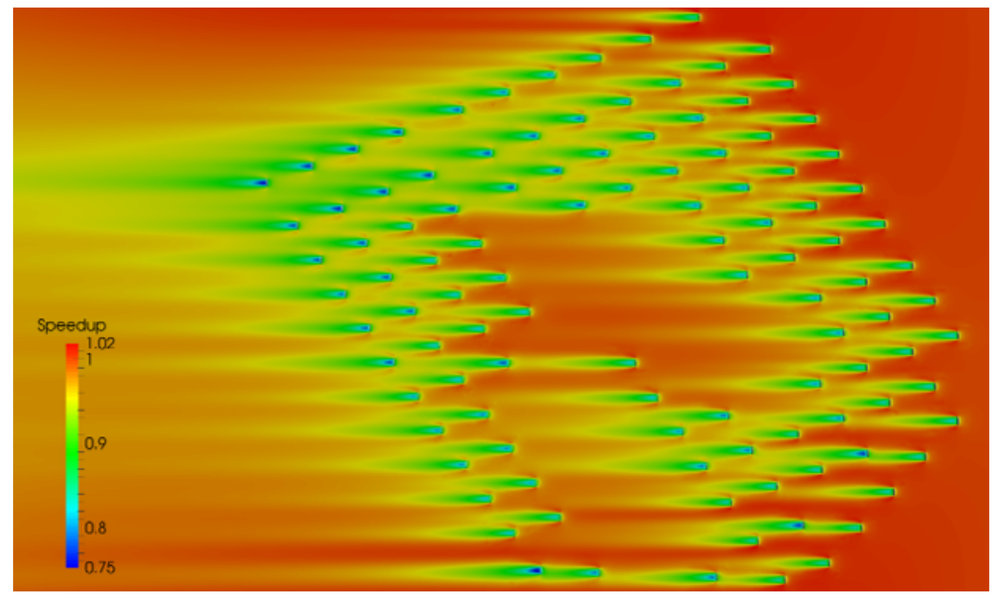
Wind farm test cases

Offshore wind farm



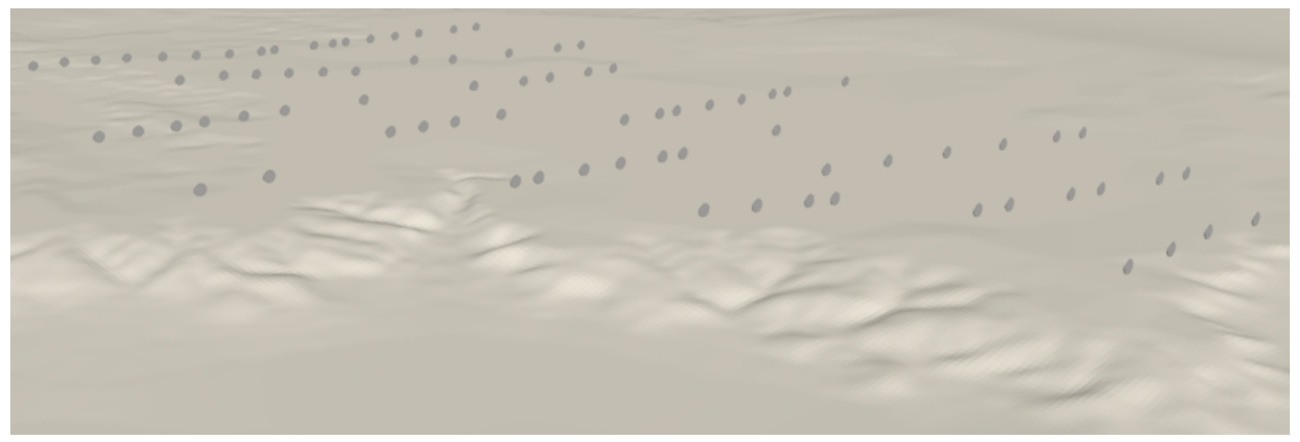
- Location: Irish sea
- #turbines: 108
- 25 million elements
- Time: 301 sec

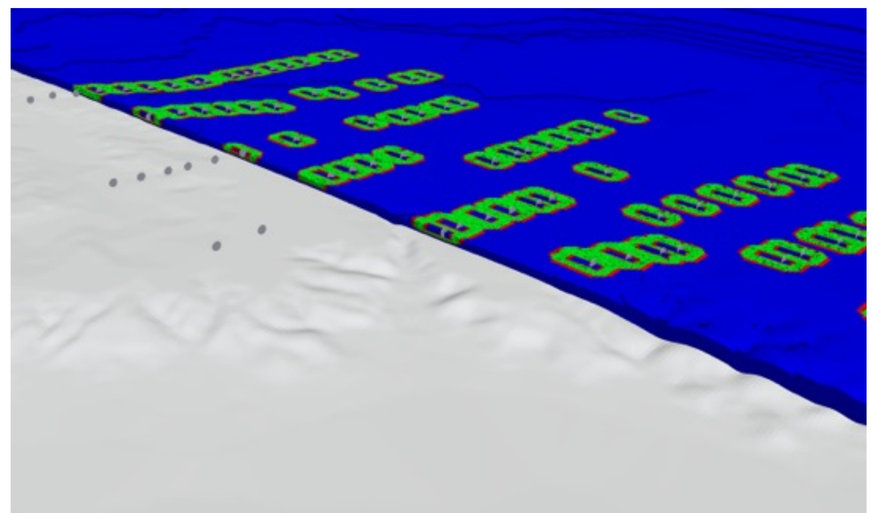
Quality stats:
- Min. qual.: 0.11
- Mean. qual.: 0.87
- Std. Dev: 0.16



Solution of the incompressible RANS equations modeling the turbines using the actuator disc theory [5], using Alya [6].

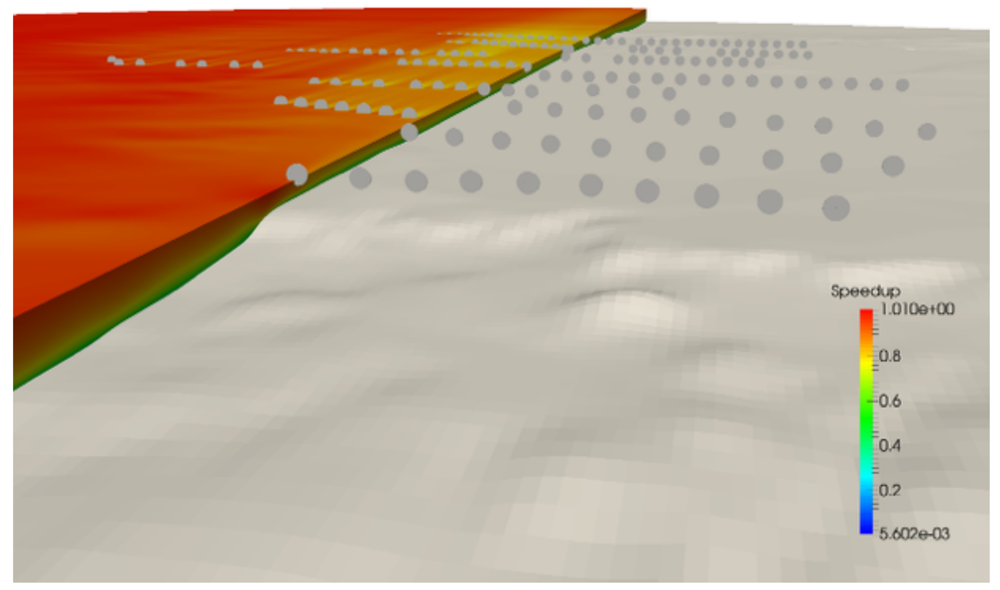
Onshore wind farm





- Location: Spain
- #turbines: 83
- 13 million elements
- Time: 122 sec

Quality stats:
- Min. qual.: 0.10
- Mean. qual.: 0.87
- Std. Dev: 0.13



Solution of the incompressible RANS equations modeling the turbines using the actuator disc theory [5], using Alya [6].

References

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